EXHIBIT 10

Artists and Illustrators Making Use of Computer Graphics

Digital Paint Systems

The development of computer graphics devices as useful tools in non-scientific fields is epitomized by the development of what are commonly known as "paint" systems. There are two primary applications for paint systems in the production of charts and slides, and in making sequences of film or videotape for the entertainment and industrial training industries. The two types of devices are distinguished primarily by the ability of one to output slides or frames of illustrations in a format compatible with television. Either type of system may be used for the other's purpose, though with less convenience than a system specifically designed for one use. This article and the accompanying survey focus upon those systems used in video applications. CGW will continue to track the development of systems (e.g., Dicomed, Comshare Execuchart, Genigraphics, and Xerox) primarily used in static applications. The reader will discover similarities between paint systems in video applications and the pagination systems found in our feature in this issue on the printing industry. The major difference between the two areas is the need of the broadcasting industry to deal with greater numbers of images, but at lower resolution.

The concept of a paint system will not be new to those already familiar with Ivan Sutherland's Ph.D. thesis (Sketchpad) of about 15 years ago. The idea of using a graphics tablet to provide human computer interface has surfaced in a number of fields since Sutherland's original work at MIT, but its uses in cinema, video, and broadcasting are perhaps the most visually pleasing and well known. The prospect of freeing artists and illustrators from the tediously limiting tools of their art—ink, pens, and paper—is tempered by the limitations and cost of the current generation of paint systems. The recent withdrawal of the Ampex's AVA from the marketplace, for instance, demonstrates that even technological excellence may not be rewarded with patronage in recessionary times. There are, however, other benefits that will insure the continued growth of digital art systems.

The advertising industry has a well-earned reputation for developing and overusing promotional techniques. The application of graphics technologies in advertising has become one of the most fertile areas for new production methods during the past five years. Proof of this can be found in the extraordinary number of awards given for advertisements that have used effects created by computer graphics. Such publicized effectiveness in promotional communication is likely to increase the demand for computer graphics in advertising, and part of that demand will necessitate better artist/illustrator interface with computers.

Demand for computer graphics is also found in those segments of the broadcasting industry dealing with news, sports, and weather—all of which need high-quality graphics that can be economically produced in a short period of time. The needs of each of the three areas are similar in some respects (e.g., a need for diagrams for the news, and maps for the weather). CBS, in particular, has engaged in a long-standing ef-

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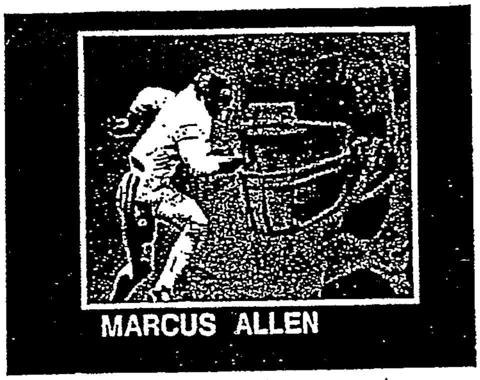

Figure 1 A sports illustration scanned into and manipulated on the Aurora Imaging System.

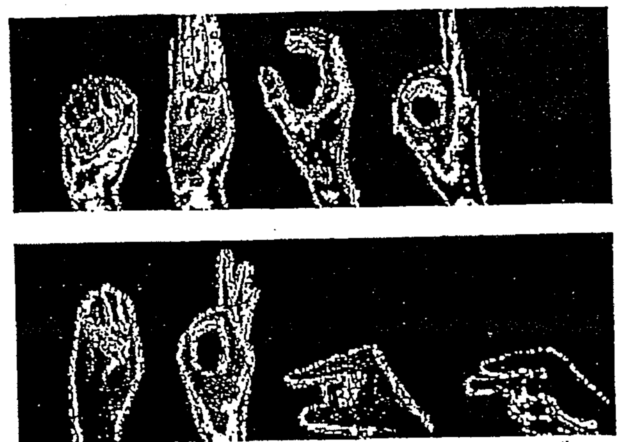

Figure 2 A scanned image is subjected to "colorizing," a digital video special effects.

DIGITAL PAINT SYSTEMS SURVEY

Manufacturer Model	Aurora Digital Video Graphics Systems	Aztek Model 20 & 30 Graphic Systems	Chyron Chyron IV Plus	Datamax UV-1	Digital Effects Video Palette III
System Configuration	DEC LSI 11/23; 15"×15" tablet; 20" RGB monitor for display; 20" color monitor for menu	H-P 1000; H-P tablet 15"×15"; Lexidata frame buffer; Mitsubishi 1000 monitor	Proprietary CPU; 14"×14" tablet; keyboard; digitizing camera	Z-80 microprocessor; 11"×11" tablet	Digital Equipment Corp. 11/34; Lexidata 3400 frame buffer; 11"×11" tablet; 19" Conrac color display monitor
Resolution	512 × 486	480 × 640; 1024 × 1280 in two configurations	264 × 144 in background; foreground is run-length encoded	525 lines	512 × 512
Character Generation	2 fonts available; user may design unique fonts	User-definable character set; 14 fonts in system plus custom fonts	50-font library available	8 fonts available; user may design fonts	N/A
Animation Capabilities	Color cycling; auto sequencing	Color cycling and sequencing	Sequencing	"Real-time" animation; color cycling; sequencing	Color cycling; auto sequencing frame-at-a-time onto a Dicomed
Colors in Palette/Display	32/256	4096/256 or 256/16	512/16; 64 for edges; 1 per character; 7 per logo	256/4, 8 or 16 depending on use	16 million/256
Brush/Paint	Artist designatable brushes, 8 storable on menu, no limit on the number available	1 to 100 pixels in 10-increment levels	4 to 6 widths available	User may designate brushes	Artist designated brushes, up to 500 storable; no limits on the brushes; standard set of symbols
Image Library	10 to 20 images on disc	256k-byte internal memory	One internal	24 bit store, can be divided into 12, 2-bit planes	One internal in buffer
Price	$115,000 to $200,000	$75,000 & $98,000	$79,000; tablet addition, $1,000	$6,595	$125,000
Special Features	Different storage capacities available; other options for output	Can support 4 additional work stations; 12 low-cost stations; video digitizer; compatible with all camera systems	Newly designed station provides separate image display monitors to be combined in boolean fashion; new text can be read onto screen continuously		Interface for film, video or both; photo-digitization option; custom software development
Remarks	Aurora Imaging Systems Richard Shoup 185 Berry Street San Francisco, CA 94107 (415) 777-2288	Aztek Data Systems Phil Lippencott 23265 South Pointe Drive Laguna Hills, CA 92653 (714) 770-8406	Chyron David Bucker 265 Spagnole Road Melville, NY 11747 (515) 694-7137	Datamax, Inc. 2256-B Landmeir Road Elk Grove Village, IL 60007 (312) 981-8205	Digital Effects, Inc. Judson Rosebush 321 West 44th Street New York, NY (212) 581-7760

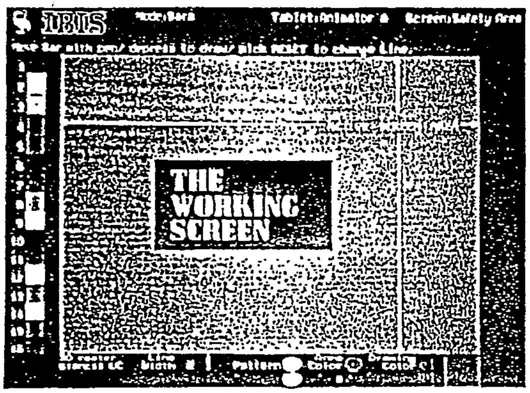

Figure 3 The working screen, including color palette from Morgan-Fairchild's IBIS system.

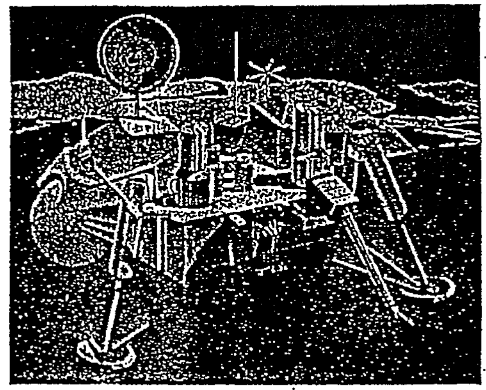

Figure 4 Display of the manned moon lander produced on Logica's Flair system.

Dubner CBG-2	For-A-Corp FVW-910	Gravitronics GDS	Interand Telestrator Electronic Graphics System	LogE/Interpretation Systems VIEW	Logica Flair
8080 Intel, 2901 bitslice processor; 11"×11", or 15"×15" tablet; monochrome menu monitor; 2 output ports for color signals	Z-80 microprocessor; lightpen; direct palette to device interface	CPU-Data General — Eclipse/Nova; Ramtek 6000, AED 512, or Ramtek 9400 (6K, to 12K, to 25K) s; tablet — 36"×48" or custom	Multiple microprocessors; proprietary frame buffer	DEC LSI 11/23; trackball/function key cursor manipulation; interface to tablet available; RGB 19" monitor; monochrome monitor	Intel 8085 microprocessor; 16"×12" article; 20" RGB monitor
525 x 1024	384 × 224 (NTSC); 384 × 256 (PAL)	512 × 512; 1280 × 1024	512 × 512 to 4096 × 1600 on different systems	512 × 512 or 1024 × 1024	785 × 575
User may design fonts; all lettraset fonts may be used	None	User can design fonts; 3 fonts internal; custom fonts available	Fonts can be designed; systems have different character set capabilities	One character set in 4 sizes; user may design character fonts	1 font in 3 sizes; user may designate fonts
Sequencing at 60 frames per second	None	Color cycling; plane switching/reveal	Sequencing; color cycling	Color cycling, sequencing	Color cycling
512/64	7/7	64/16 to 4 million/256	64 to 4096	16 million/4096	16 million/256
User-designatable brushes	2 brushes; 1- and 3-pixel widths	1 to 5 pixel width; user can designate other brushes	N/A	Cursor with 1 pixel line or window brush; 2×2 pixels to screen width	Brushes designatable by user; standard widths
2 images internal	One image internal	32 bit store; different planes within 32 bits	3 in internal memory	4 images internal	1 internal
$78,000 to $100,000	$6,500 to $7,100	$40,000 to $80,000	$12,000 to $60,000	$80,000	$80,000 to $90,000
	N/A		Model 100 — for sports/weather/news; Model 440 — for more color, logos, better image store; Model 880 "Magician" — for video line art	N/A	Menu on tablet; mirror imaging; overlay function
			Patents pending on display technology		
Dubner Computer Systems Inc. Harvey Dubner 158 Lindwood Plaza Fort Lee, NJ 07024 (201) 592-6500	For-A-Corp T. Hitota 1680 North Vine Street Suite 201 Los Angeles, CA 90028 (213) 467-8412	Gravitronics Wolfgang Baer 3014 Shattuck Avenue Berkeley, CA 94705 (415) 644-2230	Interand Corp Erik Lunkenheimer 666 North Lakeshore Drive Chicago, IL 60611 (312) 943-1200	LogE/Interpretation Systems Inc. Richard Pendergrass 6322 College Blvd. Overland Park, KS 66211 (913) 642-8700	Logica, Inc. Richard Veith 666 Third Ave. New York, NY 10017 (212) 599-0828

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Figure 5 A typical advertisement application of the Spectra digital paint system.

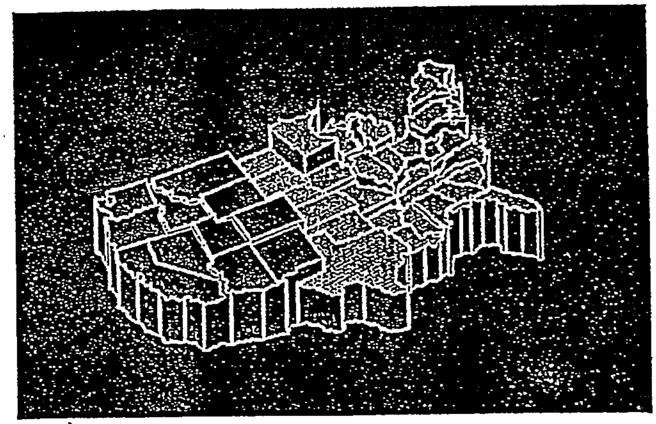

Figure 6 A business application of the LogE Compuslide system.

DIGITAL PAINT SYSTEMS SURVEY

Manufacturer Model	McInnis-Skinner Weather Graphics	Morgan-Fairchild IBIS	Norpak IPS-2	Northern Telcom VIPS	NYIT IMAGES
System Configuration	Hewlett-Packard 1000 minicomputer; monochrome menu monitor; Genisco color raster display, GCT-3000; 17"×17" tablet; 12" color monitor	Ramtek 6214 color terminal; 11"×11" tablet	Manufacturer-designed console; DEC, LSI 11/03; 13" RGB monitor; 13" monochrome menu monitor; optional tablet	Cromemco 3; monochrome menu monitor; color, RGB electro-chrome display monitor; tablets — capacitance/or pressure sensitive	DEC PDP 11/23; Genisco/NYIT frame buffer; 14"×14" tablet; 12" monochrome monitor; 19" RGB monitor
Resolution	640 × 480	640 × 480	200 × 256	256 × 256	512 × 487
Character Generation	Univers; Helvetica; Futura; other lettraset fonts; user may design fonts	5 fonts available (Helvetica, comtina, stencil); user may design fonts	2 sizes of font internal; user may design fonts	None	20 fonts available
Animation Capabilities	Color cycling; sequencing	Color cycling; sequencing	Page cycling for animation effect	None	Color cycling; sequencing; replay of previously designed frames
Colors in Palette/Display	4096/256	64/16	16/16; 6 colors, 8 grey shades, B&W	4069/16	16 million/256
Brush/Paint	User may design any width brushes; up to 1500 symbols/brushes may be stored	3 brush types — straight lines, 1 to 32 pixel brush width; line duplication function "polyline"	User can designate "brushes"; standard brushes are circles, lines, polygons	Line drawing for entry of geometric primitives; no "brushes" as in other systems	Artist may designate unique brushes; up to 50 may be stored in system
Image Library	8 images internal	1 internal; up to 20 images per disk	1 frame internal		10-byte internal memory; 1 image in frame store
Price	$68,700	Software $15,000; hardware $28,000	$17,500; tablet $1,800	$18,000 to $24,000	$105,000
Special Features	N/A	N/A	Text editing; mini-data base	Built-in modem with automatic dialer for videotex	Paint mode allows designer to exceed resolution of display device; animator software; special effects software
Remarks			One of two paint systems used for Telidon	System used for Telidon page creation	
	McInnis-Skinner Ron Hudson 6529 Classen Blvd. Oklahoma, Blvd, OK 73166 (405) 848-4246	Morgan-Fairchild Emeline Matthews 4224-A University Way N.E. P.O. Box 5475 Seattle, WA 98105 (206) 632-1374	Norpak Ltd. Ian Hembry 10 Hearst Way Kanata, Ontario K2L 2P4 Canada (613) 592-4164	Northern Telcom John Yeomans 33 City Center Drive Mississauga, Ontario L5B 2N5 Canada (416) 275-0960	NYIT Computer Labs Inc. Marco Cardamone 405 Lexington Ave. 59th Fl. New York, NY 10023 (212) 399-8398

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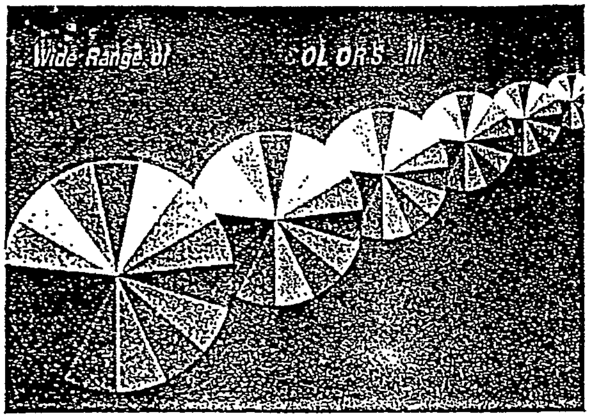

Figure 7 Color wheels produced on the Aztek system, demonstrating its brush duplication feature.

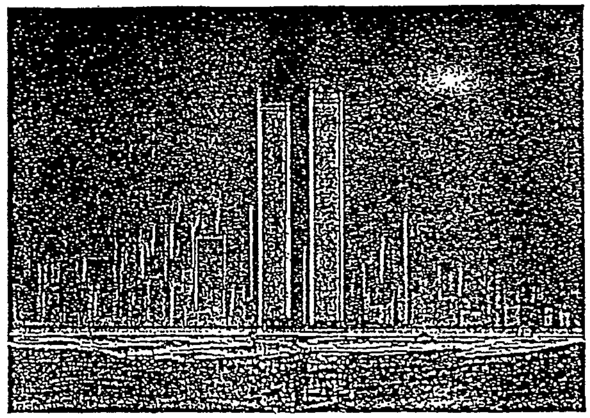

Figure 8 Manhattan Skyline produced on Digital Effects Video Palette III, artist, Mark Lindquist.

Ramtek-Xiphias Videograph	Research Machine 380Z Jackson	Spectra Computer Systems S1010 Digital Art/ Paint System	Via Video System One	Vidifont Graphics V Thompson CSF	Weathermation System II
Z-80A micro; Ramtek 6214 color terminal; 15"×15" tablet; 13" RGB menu/display monitor	Z80 microprocessor; joystick; 12" RGB monitor; dual floppy-disk drive	Chromatics CG series bases; 15"×15" tablet; 15" RGB monitor; HD 1010 disk drive	Z80-based console; 15"×15" tablet; 9" monochrome monitor, 13" color monitor; camera digitizer	Multiple 6809 micro-processors; 11"×11" tablet; 19" color display monitor	Multiple Z-80 processors; 11"×11" tablet; 12" monochrome menu monitor
640 × 512	625 × 480	512 × 512	756 × 484	512 × 1088	640 × 480
Helvetica, Futura plus 8 other fonts; user can design fonts	1 set available; user may design set	Any lettraset font is producible; user may design fonts	5 fonts in system; all lettraset fonts can be digitized	User can design fonts; custom fonts provided	User can design fonts
Color cycling; sequencing	In-betweening	Sequencing	Color cycling; sequencing	Color cycling; sequencing; scaling of figures	Color cycling; sequencing
64/16	255/11	80/80	4096/16	4096/64	256/16
Brush 1 to 128 pixels in width; 1536 storable symbols in a number of menus; custom brushes designatable	User designatable from 1 to 300 pixels	1 to 5 pixel widths; artist may design brushes	16 sizes, 1 pixel to many pixels	1 to 12 pixel width; artist may designate brushes	N/A
Internal image store holds 2	32k or 56k RAM	1 image internal	½ megabyte internal memory	2 frames internal	1 frame
$50,000 or less	$13,000	$80,000	$35,000 to $60,000	$68,500	$27,000 for radar display; $36,000 for graphics; $47,000 for both
Menu prompting; on-line help files	Operates on PAL (625 lines) and UK voltage	NTSC output; interfaces to weather services for radar map	Direct video output; 7 picture planes allow 7 images to be overlaid at once	NTSC/PAL/RGB output; mirroring	Accesses national weather service or uses radar display
Xiphias Peter Black 233 Wilshire Blvd. Suite 900 Santa Monica, CA 90401 (213) 399-3283	Royal College of Art Computer Art Bryan Smith London SW 7 United Kingdom 01-584-5020	John Welland 391 Chipeta Way Research Park Salt Lake City, UT 84108 (801) 581-5478	Via Video Matt Blum 10115 S. DeAnza Blvd. Cupertino, CA 95014 (408) 996-2055	Thompson CSF-Broadcast Thomas Hindle 37 Brown House Road Stanford, CT 06902 (203) 327-7700	Weathermation Graphics Inc. Bill Smith 190 N. State Street Chicago, IL 60601 (312) 263-6921

fort to enhance its broadcasts with clear and entertaining graphics. This has necessitated maintaining a staff of highly-talented illustrators and designers who can be called on to create materials as needed.

Because of the nature of the news today—being global in its coverage and having a multiplicity of topics—the demands for graphics are continuously changing. A minor topic in one newscast may become a major news item within a short period of time, and require major illustrative supplementation. Thus, the ability to quickly produce graphics that can convey complex subject matter becomes crucial to effective communication.

Another need relates to the intense competitiveness that characterizes coverage. As news programs have become a major source of income for the networks, graphics that can attract and hold viewer attention have become a paramount concern. CBS responded to these concerns by gathering some of the most capable graphics illustrators available, and by building a well-indexed library of graphics (both paper and digital disk-stored) that it could use for broadcasts or take apart for utilization in the design of new materials. Maps and photographs are two graphics that lend themselves to efficiencies in storage and reuse. As increased demand in the marketplace and lower equipment costs caused continued introduction of digital technology into broadcasting, a group of developing technologies from Xerox and Bell Research Laboratories came to the attention of CBS. It was CBS that provided the commercial impetus and widespread introduction of paint systems into broadcasting.

Much earlier, Richard Shoup had been asked to participate in the establishment of Xerox's Palo Alto Research Laboratories by becoming a resident scientist. While at Carnegie Mellon University, Shoup had been exposed to the work of Leo Harrison who had developed analog computers for use in video—long before digital techniques were suitable for video applications. It was this that inspired his efforts to build a digital video system. He was to spend nearly nine years developing what have come to be known as digital paint systems. One of his colleagues at Xerox, Alvery Ray Smith, later helped to develop the computer graphics laboratory at the New York Institute of Technology (NYIT), which now markets its own paint system (the basis for Ampex's AVA).

It was Shoup who personally built one of the first digital frame buffers to support the Xerox system, and by 1973 the system itself was operational. Similar work had produced a system at Bell Laboratories under the guidance of Knowlton and Miller, and at MIT. Shoup's system, called "Superpaint" at Xerox, gained its reputation through two applications — one for a California television series called "Over Easy," and the other to illustrate NASA's Venus flights. As Shoup's ability to design a system began to outgrow the limits of research at Xerox, he formed a partnership with artist Damon Rarey and started Aurora Imaging Systems. Already referred to by many as the "father" of paint systems, it was Shoup's work at Aurora that produced one of the most facile menu-operated systems on the market.

Shoup has outlined for Computer Graphics World, the principles of design that have guided his development of a paint system, or as he calls it a "video-graphics" system. Foremost among his opinions (and reflected in this issue's articles by Lansdowne and Watkins) is that the system is a tool for artists. Artists, generally, know little about computers and cannot be constrained by a machine's limitations if tight-production deadlines are to be met. Fortunately, the Aurora system has multiple monitors that allows the artist to view both the menu and the art. The menu itself is entirely graphical, allowing the artists to forego interacting with a keyboard for all but the system's initialization.

Another important feature is the interactivity of the system, which to Shoup means its capacity for real-time animation. There are a number of methods used by paint systems to create animation, at least one of which (color cycling) was developed and popularized by Shoup. In simple terms, color cycling means that a color table is used to assign (most often at random) different colors to specific pixels, giving a design the appearance of movement. This "color cycling" is used to achieve a number of effects such as stepwise motion and "reveal" animation.

A well-known animation effect of some paint systems is "history" playback (history files record the actions entered into the processing file of a computer). In this technique, an artist can create an object through a number of steps. For instance, having entered the command sequence for the creation of a tree, the commands could be replayed in rapid sequence—presenting the visual effect of animating the creation of the tree. Some animation work, such as that at Ohio State University, is accomplished through replaying stored images on hard disk. Frames of images are continually set up in the frame buffer, and displayed.

The third technique, used to create filmed-animation sequences with paint systems, is to interface a camera (e.g., a Dicomed or Celco film recorder) or video tape recorder with the system. The individual frames are then recorded as they are created. Recently, magnetic video disks have become available that are capable of recording these individual frames. However, their cost and limited storage ability prevent widespread use.

Real-time generation of animation is used in the simulation industry to produce massive amounts of imagery, but at substantially lower resolution. The need for resolution, however, may vary from one application to another. In some cases, an Apple computer may suffice, but for

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most broadcasting and advertising applications high quality is required. This means that anti-aliasing or filtering techniques must be applied to images before they can be used.

One final aspect of system design mentioned by Dr. Shoup is the need to provide flexible configurations. Most important, is the ability to provide multiple-access terminals to the computer's memory. In a broadcasting environment, for example, it might be desirable to provide access to the system in an editorial suite for review purposes. One might also want a system that allows for multiple users through terminals and memory additions.

In compiling the information for the accompanying survey, several important controversial aspects of paint systems became evident. One of the most prominent of these is the description given to system paint or brush methods. Basically, the term brush is used to describe the user's ability to paint on the CRT in color. The term is appropros because of the physical similarity between a paint brush and a tablet wand when the wand is used to apply color to the CRT. There are two distinctive types of tablet interfaces for paint systems: Capacitance systems that may only duplicate a color that is assigned to them, and pressure-sensitive tablets that produce different saturations of color—depending upon the artist's brush pressure. One user lamented a manufacturer's attempts to describe a system as having the qualities of an airbrush. His feeling is that electronic brushes are in no way comparable with airbrushes, and that manufacturers are deliberately misleading purchasers with such claims. The ability of a user to create unique brushes appears to be the most important consideration, along with the availability of different brush widths.

There are widely varying opinions as to the range of colors needed in paint systems. One side says that the artist needs to have a system that will allow as wide a creative range as would be available through additional means, while the other points out that since television displays have a practical limit of 32 colors, that the 16 million-color capacity described by manufacturers with 8-bit pixel depth is largely superfluous. One system-developer has remarked that these colors cannot be broadcast by or recorded on standard television—a point that would seem to support those who describe the millions of colors as a market promotion. While there is probably no definitive answer to this question, one can appreciate the creative needs of artists and illustrators who want to be able to blend and mix their colors to achieve specific effects.

Most systems allow original art work or backgrounds to be scanned directly into the display image or the frame buffer (see *Figure 1*). This underscores the efficiencies introduced through the use of digital-input technologies. There is an enormous body of existing artwork, available to designers through video digitization, that can be suitably manipulated for specific purposes. The digital frame store provides a function similar to the artist's canvas. Video signals can be sent to this "canvas" from the graphics tablet or a digital-storage medium. The advantage of the frame store is that it provides the artists with pixel memory in which color planes may be stored and manipulated. Once in the frame store, an artist may subject the image to a vast repetoire of digital effects that are widely used in the video industry—e.g., flipping, replication, compression, and colorizing (see *Figure 2*).

Systems considered in the accompanying survey are primarily menu based, and almost all of them have a number of similar features. Most common of these is the use of "fill" algorithms to allow polygonal spaces to be filled by an operator-designed color. Method and speed of filling may differ from one system to the next, depending upon the formula used. Most of the systems have the capacity to produce RS-170 video composite and NTSC signals. Some produce RS-232 signals for computer-to-computer communications, or for communication between multiple monitors within a system. Some of the more advanced systems have truly unique features. The MCI/Quantel digital fine art system (not included in the survey due to the unavailability of technical specifications) has a color recognition capability similar to that found in advanced pagination systems. This capability allows the artist to assign to the cursor controller any color already present in the display, greatly enhancing the designer's ability to touch-up parts of the image. IMAGES, the NYIT-produced system, has the capacity to produce the effect of multiplanar animation cameras — with several planes available for overlay. Others, such as Logica's Flair, feature commands that allow the artist to split the screen and duplicate the display in a "mirror" fashion. The Weathermation system, originally developed to provide weather graphics, has since expanded into other areas. Two of these systems can interface with output from the National Weather Service to display their radar scans. Finally there are two systems that are used to produce Telidon images. Both appear to be relatively simple, due to their need to produce displays that are suitable for transmission over telephone lines.

As the use of electronic media for communication increases, we can expect further development in digital paint or digital fine art systems. The lesson of AVA has not been lost, and we are likely to see systems designed that will fill specific market niches. We are also likely to see different disciplines (e.g., publishing, animation, and computer-aided design) borrowing techniques from one another in order to resolve present system limitations. ■

Jerry Borrell

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EXHIBIT 11

5 of 15 DOCUMENTS

Computerworld

March 29, 1982

SECTION: COMMUNICATIONS; Pg. 42

LENGTH: 105 words

HEADLINE: EX855 **Video Printer** Released by Axiom

DATELINE: SAN FERNANDO, Calif.

BODY:

A printer that reportedly produces hard copy from computer terminals, graphics terminals and video monitors has been unveiled by Axiom Corp.

The Model EX855 **Video Printer** promises high resolution of up to 650 dot/line and can reportedly transcribe any character size or font and foreign and scientific symbols. It copies the composite video information displayed on the screen onto electrosensitive paper and requires a single connection to a standard video jack.

The EX855 **Video Printer** is unitpriced at S1,595 and quantity discounts are available, the vendor said from 1014 Griswold Ave., San Fernando, Calif. 91340.

EXHIBIT 12

DEC disk history
Started 1/94 -pb
Phil Budne <phil at ultimate.com>

$Id: dec.disks,v 1.26 2004/03/15 15:20:03 phil Exp $

The focus is on disks sold for use on DEC systems (whether manufactured by DEC or not) not general market peripherals (ie; the DSP SCSI line) manufactured by DEC.

Capacity is approx, (1K=1024 1M=1024K) some formatted, some unformatted
Geometry is (usually) physical (counts alternate sec & cyl)
~ on cylinder counts means average (zone bit recorded disk)

Transfer rates are (usually) avg sustainted rates to/from media.
1K=1000, 1M=1000K, b=bits, B=8-bit bytes.

All hard disks 3600 rpm unless noted

Wanted:
- corrections & additions!!
- seek times (avg/min/max)
- rotational latency
- transfer rate
- origal mfgr & designation for non-dec disks
- interface type (ie; Massbus, MSCP) or controller type
- year of introduction (dec or orig mfgr)
- encoding?? bpi??

Old interfaces (removable unless noted)
======================================

disk	cap.	sec/trk	trk/cyl (surf)	cyl	notes
================ VAX730 IDC					
R80	121M	31	14	559	dec built; winchester; SMD interface (RM80 with SMD/Massbus converter)
================ via PDP-11 RK-11, PDP-8 RK8					
RK02	1.2M	12	2	203	Diablo model 30 low density (256B sect) avg seek: 70ms (15ms min) 1500 rpm; avg rot delay: 20ms xfer: 22.2us/word 1100 BPI max
RK03	2.5M	12	2	203	Diablo model 30 high density (512B sect) avg seek: 70ms (15ms min) 1500 rpm; avg rot delay: 20ms xfer: 11.1us/word 2200 BPI max
RK05(J)	2.5M	12	2	203	1500rpm; RK03 cartridge; RK8 max xfer 1.44Mb/s (8.32us/wd 1.1??) seek: 50ms/10ms/85ms
RK05F	5M	12	2	203	1500rpm; fixed rk05; 2xRK05 to s/w
================					
RK06	13M	22	3	411	2400rpm; dec built

```
RK07     27M      22       3        823      2400rpm; dec built;
                                             xfer 538KB/s; lat=12.5ms
                                             seek: 36.5ms avg, 8.5ms min
                                             avg access 49ms

================

RL01     5.2M     40       2        256      2400rpm; 256B/sect; dec built; pack
                                             xfer 512KB/s; lat=12.5ms
                                             seek (ms) 55avg/15min/100max
                                             3725 BPI; 125 TPI
RL02     10M      40       2        512      2400rpm; 512B/sect; dec built; pack
                                             xfer 512KB/s; lat=12.5ms
                                             seek (ms) 55avg/15min/100max
                                             3725 BPI; 250 TPI

================ via PDP-10 RA10

RB10     20-100M 11        varied            "Giant Bryant" disk
                                             (aka "MD10" Moby Disk???)
                                             1200rpm? av seek 110ms?

================ via PDP-10 RC10;

RD10     2.5M     20       2        100      Burroughs disk
                                             1800(1735)rpm; 32*36b/sect
                                             fixed head; lat=17.6ms; xfer=2.7Mb/s
                                             (76000W/S; 13us/W)
                                             total of 512,000 36-bit words
                                             (4000 128-word blocks)
                                             200 tracks of 80 32W "segments"

RM10B    2.07M    30       1        90       Bryant drum; 64*36b/sect; xfer 7.9Mb/s
                                             @60Hz: 3450rpm, lat8.8ms
                                             @50Hz: 2870rpm, lat10.6ms
                                             total of 345,600 36-bit words
                                             (2700 128-word blocks)
                                             Drum surface was conical, and mounted
                                             vertically.

================ fixed head

RF/RS11 512K      --       1        128      1800rpm; fixed head

RS08     256KW    --       1        128      PDP-8 fixed head disk (RF08 ctrlr)
                                             128 fixed heads (1/track)
                                             3(+3 spare) timing tracks
                                             word addressable
                                             2048 words/track; 1100 BPI max
                                             @60Hz: xfer 16us/wd
                                                    access 16.9ms/250us/33.6ms
                                             @50Hz: xfer 19.2us/wd
                                                    access 20.3ms/320us/40.3ms
                                             max density 1100BPI, NRZI recording

DF32     32KW     --       1        16       PDP-8 fixed head disk (13 bit words)
                                             word addressable; 2KW tracks
                                             @60Hz: xfer 32us/wd, avg access 16.67ms
                                             @50Hz: xfer 39us/wd, avg access 20ms
                                             max density 1100BPI, NRZI recording
                                             10" rack 10.5" high
```

```
                                        Upto 3 DS32 slaves can be chained.

================ via PDP-10 RP10; PDP-11 RP-11; PDP-8 RP08

RP01    5M      5       10      203     2400rpm; Memorex ("Mark I"?)
                                        pack [never released]
                                        seek (ms) 50avg/20min/80max; lat13.7ms
                                        xfer=837Kb/s
RP02    20M     10      20      203     2400rpm; Memorex 660 (Mark IV); pack
                                        seek (ms) 50avg/20min/80max; lat13.1ms
                                        xfer=1.8Mb/s. $25k c. 1969
RP03    40M     10      20      400     2400rpm; Memorex (Mark VI); pack

================ via PDP-6 270

5022    5.76MW  4/7     16      128/128 Data Products disk
                                        inner and outer zones
                                        each arm has heads for both
                                        128 (36 bit) word sectors

□
Massbus
=======
disk    cap.    sec/trk trk/cyl cyl     notes

RP04    83M     22      19      411     pack; ISS-Sperry Univac (8430?)
                                        3500rpm? av seek 27ms?

RP05    83M     22      19      411     pack; Memorex; drive looks like RP06
                                        field upgradable to RP06

RP06    176M    22      19      815     pack; ISS/Memorex 677 "Mark XVI"
                                        ("Merlin"?) (clone of IBM 3330-II?)
                                        avg access 38.3ms; avg lat 8.3ms
                                        seek 30ms (avg), 10ms (min)
                                        xfer=825KB/s
                                        3600rpm

RP07    504M    50(30?) 32      630     ISS/Sperry Univac; winchester
                                        seek 23ms (avg) 3633 rpm?
                                        xfer=2.3MB/s (36-bit)/ 1.3MB/s (32-bit)

RP20    929M    24(25?) 30      1119(750?) two fixed spindles (on DX20?)
                                        seek 25ms (avg); xfer=1.3MB/s
                                        3500 rpm? (840000 128*36b blocks)
                                        Memorex 3652??
                                        dual Memorex 3650 (IBM 3350 clone)

RS03    512K    64      1       64      fixed head; 128B/sector
RS04/5  1M      64(32?) 1       64      fixed head; 256B/sector
                                        6ms access; spiral read
                                        32 blks/trk 2048 blks/cyl?
                                        3600rpm

RM02    67M     32      5       823     pack; CDC 9762; 2400 rpm
                                        xfer=6.4Mb/s (806KB/s); avg acc 42.5ms
                                        seek 30ms (avg), 6ms (min)
                                        avg latency 12.5ms
RM03    67M     32      5       823     pack; CDC 9762; 3600 rpm
                                        xfer=9.6Mb/s (1.2MB/s); avg acc 38.3ms
```

```
                                          seek 30ms (avg), 6ms (min)
                                          avg latency 8.3ms

RM05     256M     32       19       823     pack; CDC 9766
RM06     ?

RM80     124M     32       14       559     winchester (RA80 HDA)
                                          xfer=9.6Mb/s (1.2MB/s)
                                          avg access 33.3ms; avg lat 8.3
                                          seek 25ms (avg), 6ms (min)
                                          3600RPM

ML11A    varies   -        -        -       solid-state (ram) disk; 2MB/s xfer
                                          1-31 arrays of 512 or 2048 blocks ea

MSCP/SDI
========
disk     cap.     sec/trk  trk/cyl  cyl     notes

RA60     205M     42       4        2382    pack; seek 42 ms (avg);
                                          xfer=2.1MB/s (1.98?)
                                          3500 rpm?? 5 platters?

=== 5.25" FH?

RA70     280M     33       11       1507
RA71     684M     51       14       1915
RA72     1G       51       20       1915
RA73     2G       70       21       2667

=== 19"

RA80     124M     31       14       546     dec; winchester; 3500 rpm?
RA81     446M     51       14       1248    dec; winchester; 3500 rpm?
                                          seek 28 ms (avg); xfer=2.3MB/s
RA82     608M     57       15       1423    dec; winchester

RA90     1.2G     69       13       2649
RA92     1.5G     69       13       3279

RC25     26M*2    42       4        302     "LESI" (Low End Storage Interconnect)
                                          1 fixed, 1 removable; CDC9457? ("Lark")
                                          Peak xfer 1.25 MB/s;
                                          Seek 10/35/55ms
                                          avg rotational latency: 10.5ms
                                          avg access: 45.5 ms

MSCP/DSSI
=========

RF30     143M     37       6        1320    5.25" HH
RF31     380M     50       8        1861    5.25" HH
RF35     852M                               5.25" HH?
RF36     1.6G                               5.25" HH?
RF71     390M     37       16       1320    5.25" FH
RF72     1G       50       21       1861    5.25" FH
RF73     2G                                 5.25" FH?
RF74     3.5G                               5.25" FH?

=== ??
```

AX204949

ESE20	120M	4	128	483	Solid state disk

Floppy

disk	cap.	sec/trk	trk/cyl	cyl	notes
RX01	256K	26	1	77	8" SSSD (IBM soft-sectored) 128B/sect; 360rpm xfer 250Kb/s; lat 83ms seek (ms) 405avg/30min/790max
RX02	512K	26	1	77	8" SSDD (on-standard) 256B/sect; 360rpm xfer 488Kb/s (61KB/s); lat 83ms seek (ms) 154avg/6min avg access 262ms
RX03	1M	26	2	77	8" DSDD (non-standard) -- not released
RX22					
RX23					3.5" SCSI
high	1.4M	18	2	80	
double	720K	9	2	80	
single	360K	9	2	40	
RX26					3.5" SCSI
extra	2.8M	36	2	80	
high	1.4M	18	2	80	
double	720K	9	2	80	
single	360K	9	2	40	
RX33					5.25" Teac FD55-GFR-17U MFM?
extra	1.2M	15	2	80	
high	720K	9	2	80	DSDD
double	400K	10	1	80	SSDD (RX50 compat?)
single	360K	9	2	40	DSSD
RX50	400K	10	1	80	5.25" single sided, dual drive FM encoding

□

MFM "ST506/412 interface" (on RQDX{1,2,3})

disk	cap.	sec/trk	trk/cyl	cyl	notes
=== 5.25" FH					
RD50	5M	17	4	153	Seagate ST506 seek 85/3?/??
RD51	10M	17	4	306	Seagate ST412 seek 85/16.6?/??
RD52	31M	18	7	480	Quantum 540 / ATASI 3046 (also Evotek?)
RD53	71M	18	8	1024?	Microp 1325 (or 1335) w/ jumper at J7
RD54	156M	17	15	1225	Maxtor XT-2190D
=== 5.25" HH					
RD31	20M	17	4	615	ST225 seek (ms) 65/20/150
RD32	40M	17	6	820	ST251(-1*) seek 40(28*)/8/70 ST277R(-1*) [MFM format] 40(28*)/8/70
RD33	71M				Microscience HH-1090 [Never released]

SMD disks popular on VAXen (Winchesters unless noted)

disk	cap.	sec/trk	trk/cyl	cyl	notes
A9300	248M	32	19	815	Ampex 9300; removable
A330	262M	32	16	1024	Ampex Capricorn 330
CDC9720	275M	48	10	1147	
CDC9730	268M	32	10	823	removable
CDC9762	65M	32	5	823	removable; (also RM03) [phys 80M?]
CDC9766	256M	32	19	823	removable; (also RM05)
CDC9775	839M	32	40	843	
M160	132M	32	10	823	Fujitsu 160
M2351	337M	46	20	842	Fujitsu Eagle 19"
M2351A	337M	48	20	842	Fujitsu Eagle 19"
M2351AF	337M	48	20	842	Fujitsu Eagle 19" w/ 3 fixed heads
M2361	549M	64	20	842	Fujitsu Super Eagle 19"
M2361A	549M	68	20	842	Fujitsu Super Eagle 19"
NEC800	800M	66	23	850	
NEC2363	1G	64	27	1024	

□

SCSI disks (Winchesters unless noted)

disk	cap.	sec/trk	trk/cyl	cyl	notes
=== 5.25" FH					
RZ55	325M				Micropolis 1578-15 or maxtor xt-4380sb2?
RZ55L					
RZ56	650M	54	15	1632	Micropolis 1588-15
RZ56L					
RZ57	1.01G	71	15	1925	Micropolis 1598-15
RZ57I					
RZ57L					
RZ58	1.3G	85~	15	2117	5400rpm? Micropolis 1908?
RZ59	8.9G	193	18	5111	
=== 5.25" FH?					
RZ72					
RZ73	2.0G	71	21	2621	
RZ74	3.57G	67~	25	4165	
=== 3.5" HH?					
RZ22	51M	33	4	776	Conner CP350
RZ23	102M	33	8	776	Conner CP3100-1
RZ23L	118M	39~	4	1524	
RZ24	205M	38	8	1348	Conner CP3200; 3500rpm?
RZ24L	240M	66~	8	1818	Quantum LPS-240S?
RZ25	416M	62	9	1492	
RZ25L	523M	79~	8	1891	

AX204951

```
================ 5" HH?

RZ31
RZ33     ??
RZ35     832M     57       14       2086

================ 5" FH??

RZ55     332M
RZ56     635M
RZ57     1G
RZ58     1.3G

================ 5" FH

RZ73     2G
RZ74     3.57G

================ CD-ROM (SCSI)

RRD40                                      LMS CM 210 (no audio)
RRD42                                      Sony CDU-541
RRD43
RRD44
RRD45
RRD46                                      12x
RRD47                                      Toshiba 32x
RRD50                                      Philips/LMSI CM100 (no audio)

================ Optical WORM

RWZ01    288M     31       1       18751   Erasable Optical 5.25"
                                           (Sony) EDM-1DA0/1DA1/650/600

RWZ21                                      WORM 3.5" (MO)

RV20     6GB?                              Optical WORM 12"
RSV20                                      Optical WORM
RV60                                       12"
RV64                                       Jukebox (RV20 based)

RWZ52    1.2G                              5.25"; rewritable; 600MB/side
                                           HC: acc 36ms; r 1.6MB/s; w 0.53MB/s
                                           LC: acc 38ms; r 1.0MB/s; w 0.33MB/s

RVZ72    6.55G                             tabletop 12" write once; SCSI
                                           access 600ms; read 900KB/s; w 400 KB/s
RV720    78GB                              deskside jukebox w/ 1 drive, 12 disks
RV730ZB 438GB                              datacenter jukebox w/ 2 drives; 67 d.
RV730ZD 308GB                              datacenter jukebox w/ 4 drives; 47 d.

Decimage Express v2?                       LMS 5.25"/12" WORM

Solid-state disks (SCSI?)
=========================

"disk"   cap.     sec/trk trk/cyl cyl      notes

EZ51     104M     33       9       776
```

AX204952

EZ54	418M	62	10	1492
EZ58	835M	20	10	8353

EXHIBIT 13

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hard disk

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HOUGHTON MIFFLIN COMPANY

Dictionary
hard disk
n.

A rigid magnetic disk fixed permanently within a drive unit and used for storing computer data. Hard disks generally offer more storage and quicker access to data than floppy disks do.

Computer Desktop Encyclopedia

Technology
hard disk

AX204954

The primary computer storage medium, which is made of one or more aluminum or glass platters, coated with a ferromagnetic material. Most hard disks are "fixed disks," which have platters that reside permanently in the drive. Removable disks are encased in plug-in cartridges, allowing

data to be taken out of the drive for storage or for transfer to another party. Before high-speed connections were common on the Internet, removable SyQuest, Jaz and Zip disks were routinely sent through the post office.

Two Major Categories: ATA/IDE and SCSI
Most hard disks are ATA (originally and still widely known as "IDE"). SCSI drives have traditionally been found on servers and high-performance workstations. The SCSI advantage is that up to 15 devices can be attached to the same controller board, which uses only one slot in the PC. SCSI was the first drive technology to employ fault-tolerant RAID systems. Today, ATA drives are widely used for RAID arrays. See IDE and RAID.

Both ATA/IDE and SCSI hard disks are low-level formatted at the factory, which records the original sector identification on them (see format program).

Fast Rotation

Hard disks provide fast retrieval because they rotate constantly at high speed, from 5,000 to 15,000 RPM. Either to preserve battery life in laptops or to promote longevity, hard disks can be configured to turn off after a defined period of inactivity.

It Started in the Mid-1950s

In 1956, IBM introduced the RAMAC hard disk with platters two feet in diameter that held the equivalent of 100,000 bytes. In the 1980s, desktop hard disks were introduced with 5MB using 5.25" platters (see ST506). Today's entry level drives have at least 8,000 times the capacity in the first personal computers. Platter size was reduced to 3.5" for desktops, 2.5" for laptops and 1.8" for handhelds. In 2004, Toshiba introduced the 0.85" drive (see below). See magnetic disk, floppy disk, Microdrive and CAV.

TYPES OF HARD DISKS

Type of Interface	Encoding Method**	Transfer Rate (Per sec)	Range of Capacities
ATA (IDE)	RLL	3-133MB	500MB-400GB
SCSI	RLL	5-320MB	20MB-300GB
Older Interfaces			
IPI	RLL	10-25MB	200MB-3GB
ESDI	RLL	1-3MB	80MB-2GB
SMD	RLL	1-4MB	200MB-2GB
IDE	RLL	1-8MB	40MB-1GB
ST506 RLL	RLL	937KB	30MB-200MB
ST506	MFM	625KB	5MB-100MB

** Most disks use RLL, but encoding methods are not prescribed by all interfaces.

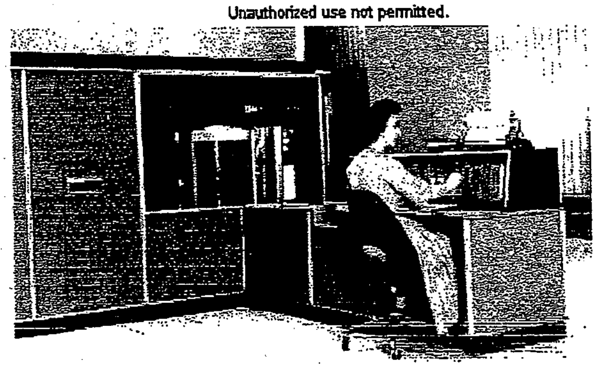
Hard Disk Measurements

AX204955

Capacity is measured in bytes, and speed is measured by transfer rate in bytes per second (see above) and access time in milliseconds (ms). Hard disk access times range from 3 ms to about 15 ms, whereas CDs and DVDs range from 80 ms to 120 ms.

Non-Removable Internal Hard Disk

Hard disks use one or more metal or glass platters covered with a magnetic coating. Although there has been a variety of removable hard disks over the years, a computer's primary hard disks are fixed inside the drive. The entire unit is removed only to be replaced or repaired. In this drawing, the cover is removed.



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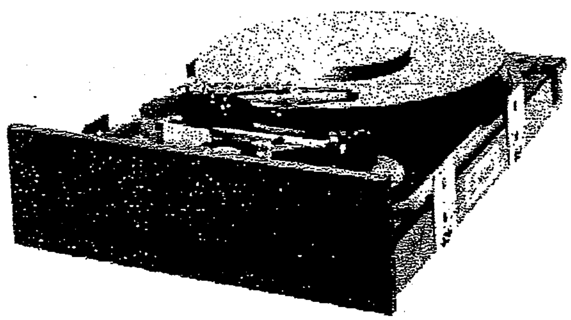
First Hard Disk

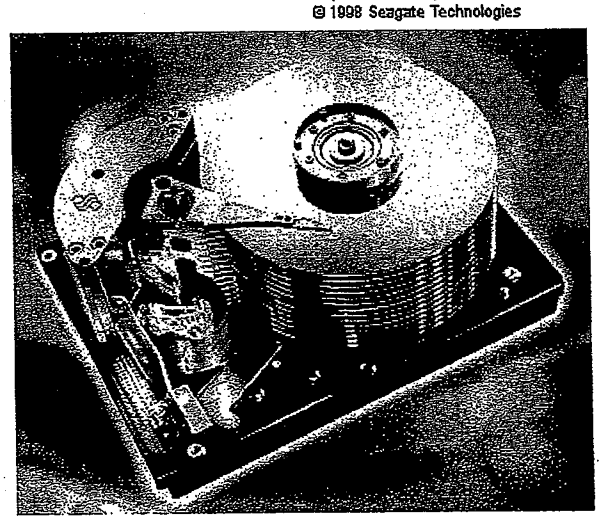
Part computer, part tabulator, in 1956, IBM's RAMAC was the first machine with a hard disk, which was extraordinary technology of the times. Each of its 24" diameter platters held a whopping 100,000 characters (they were not bytes then) for a total of five million characters. *(Images courtesy of International Business Machines Corporation. Unauthorized use not permitted.)*

AX204957



First Microcomputer Hard Disk

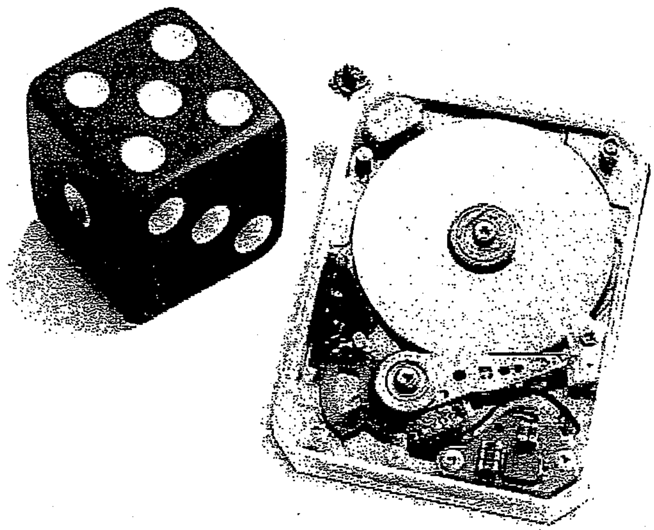
Seagate introduced the first hard disk for personal computers in 1979. At 5MB, the ST506 held 10 times as much as the RAMAC at a fraction of its size. *(Image courtesy of Seagate Technology, Inc.)*



Four Decades Later

Entry level these days, but in 1998, this Seagate drive's 47GB was impressive. Four decades of research and development let us store 100,000 times as much on the same platter surface. Even more impressive is that this much data is stored on one side of only one platter today. *(Image courtesy of Seagate Technology, Inc.)*

AX204958



A Not-Even-One-Inch Drive
In 2004, Toshiba introduced the first 0.85" hard disk with shipments of 2GB and 4GB units in 2005. Using perpendicular recording, Toshiba is expected to pack up to 8GB on this disk by 2006. *(Image courtesy of Toshiba Corporation.)*

WordNet
Note: click on a word meaning below to see its connections and related words.

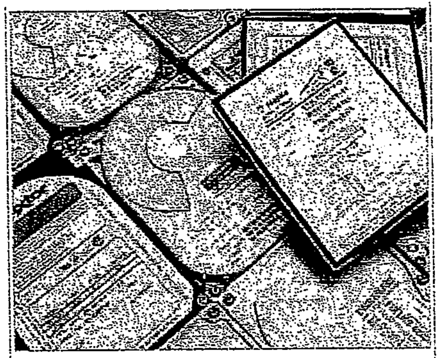
The *noun* hard disc has one meaning:

Meaning #1: a rigid magnetic disk mounted permanently in a drive unit
Synonyms: hard disk, fixed disk

Wikipedia
hard disk

A hard disk (or "**hard disc**" or "**hard drive**" or "**hard disk drive**") is a computer storage device that stores data on rotating magnetic surfaces.

Mechanics



Typical hard drives of the mid-1990s.

A hard disk uses rigid rotating platters. It stores and retrieves digital data from a planar magnetic surface. Information is written to the disk by transmitting an electromagnetic flux through an antenna or *write head* that is very close to a magnetic material, which in turn changes its polarization due to the flux. The information can be read back in a reverse manner, as the magnetic fields cause electrical change in the coil or *read head* that passes over it.

A typical hard disk drive design consists of a central axis or spindle upon which the platters spin at a constant speed. Moving along and between the platters on a common armature are the read-write heads, with one head for each platter face. The armature moves the heads radially across the platters as they spin, allowing each head access to the entirety of the platter.

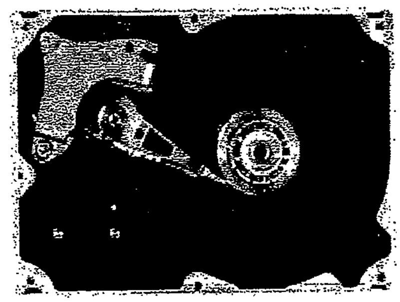
The associated electronics control the movement of the read-write armature and the rotation of the disk, and perform reads and writes on demand from the disk controller. Modern drive electronics are capable of scheduling reads and writes efficiently across the disk, and of remapping sectors of the disk which have failed.

Also, most major hard drive and motherboard vendors now support S.M.A.R.T. technology, by which impending failures can often be predicted, allowing the user to be alerted in time to prevent data loss.

The (mostly) sealed enclosure protects the drive internals from dust, condensation, and other sources of contamination. The hard disk's read-write heads fly on an air bearing (a cushion of air) only nanometres above the disk surface. The disk surface and the drive's internal environment must therefore be kept immaculately clean, as fingerprints, hair, dust, and even smoke particles have mountain-sized dimensions when compared to the submicroscopic gap that the heads maintain.

Some people believe a disk drive contains a vacuum — this is incorrect, as the system relies on air pressure inside the drive to support the heads at their proper *flying height* while the disk is in motion. Another common misconception is that a hard drive is totally sealed. A hard disk drive requires a certain range of air pressures in order to operate properly. If the air pressure is too low, the air will not exert enough force on the flying head, the head will not be at the proper height, and there is a risk of head crashes and data loss. (Specially manufactured sealed and

pressurized drives are needed for reliable high-altitude operation, above about 10,000 feet. Please note this does not apply to pressurized enclosures, like an airplane cabin.) Some modern drives include flying height sensors to detect if the pressure is too low, and temperature sensors to alert the system to overheating problems.



Hard disk drives are not airtight. They have a permeable filter (a **breather filter**) between the top cover and inside of the drive, to allow the pressure inside and outside the drive to equalize while keeping out dust and dirt. The filter also allows moisture in the air to enter the drive. Very high humidity year-round will cause accelerated wear of the drive's heads (by increasing stiction, or the tendency for the heads to stick to the disk surface, which causes physical damage to the disk and spindle motor). You can see these breather holes on all drives -- they usually have a warning sticker next to them, informing the user not to cover the holes. The air inside the operating drive is constantly moving too, being swept in motion by friction with the spinning disk platters. This air passes through an internal filter to remove any leftover contaminants from manufacture, any particles that may have somehow entered the drive, and any particles generated by head crash.

Due to the extremely close spacing of the heads and disk surface, any contamination of the read-write heads or disk platters can lead to a head crash — a failure of the disk in which the head scrapes across the platter surface, often grinding away the thin magnetic film. For GMR heads in particular, a minor head crash from contamination (that does not remove the magnetic surface of the disk) will still result in the head temporarily overheating, due to friction with the disk surface, and renders the disk unreadable until the head temperature stabilizes. Head crashes can be caused by electronic failure, a sudden power failure, physical shock, wear and tear, or poorly manufactured disks. Normally, when powering down, a hard disk moves its heads to a safe area of the disk, where no data is ever kept (the *landing zone*). However, especially in old models, sudden power interruptions or a power supply failure can result in the drive shutting down with the heads in the data zone, which increases the risk of data loss. Newer drives are designed such that the rotational inertia in the platters is used to safely park the heads in the case of unexpected power loss. In recent years, IBM pioneered drives with "head unloading" technology, where the heads are lifted off the platters onto "ramps" instead of having them rest on the platters. Other manufacturers have begun using this technology as well.

Spring tension from the head mounting constantly pushes the heads towards the disk. While the disk is spinning, the heads are supported by

AX204961

an air bearing, and experience no physical contact wear. The sliders (the part of the head that is closest to the disk and contains the pickup coil itself) are designed to reliably survive a number of landings and takeoffs from the disk surface, though wear and tear on these microscopic components eventually takes its toll. Most manufacturers design the sliders to survive 50,000 contact cycles before the chance of damage on startup rises above 50%. However, the decay rate is not linear — when a drive is younger and has fewer start/stop cycles, it has a better chance of surviving the next startup than an older, higher-mileage drive (literally, as the head drags along the drive surface until the air bearing is established). For the Maxtor DiamondMax series of drives, for instance, the drive typically has a 0.02% chance of failing after 4,500 cycles, a 0.05% chance after 7,500 cycles, with the chance of failure rising geometrically to 50% after 50,000 cycles, and increasing ever after.

Using rigid platters and sealing the unit allows much tighter tolerances than in a floppy disk. Consequently, hard disks can store much more data than floppy disk, and access and transmit it faster. In 2004, a typical workstation hard disk might store between 80 GiB and 400 GiB of data, rotate at 5,400 to 10,000 rpm, and have an average transfer rate of over 30 MB/s. The fastest workstation hard drives spin at 15,000 rpm. Notebook hard drives, which are physically smaller than their desktop counterparts, tend to be slower and have less capacity. Most spin at only 4,200 rpm or 5,400 rpm, though the newest top models spin at 7,200 rpm.

Performance

There are three primary factors that determine hard drive performance: seek time, latency and internal data transfer rate:

- **Seek time** is a measure of the speed with which the drive can position its read/write heads over any particular data track. Because neither the starting position of the head nor the distance from there to the desired track is fixed, seek time varies greatly, and it is almost always measured as an *average seek time*, though *full-track* (the longest possible) and *track-to-track* (the shortest possible) seeks are also quoted sometimes. The standard way to measure seek time is to time a large number of disk accesses to random locations, subtract the latency (see below) and take the mean. Note, however, that two different drives with identical average seek times can display quite different performance characteristics. Seek time is always measured in milliseconds (ms), and often regarded as the single most important determinant of drive performance, though this claim is debated. (More on seek time.)

- All drives have rotational **latency**: the time that elapses between the moment when the read/write head settles over the desired data track and the moment when the first byte of the required data appears under the head. For any individual read or write operation,

latency is random between zero (if the first data sector happens to be directly under the head at the exact moment that the head is ready to begin reading or writing) and the full rotational period of the drive (for a typical 7200 rpm drive, just under 8.4 ms). However, on average, latency is *always* equal to one half of the rotational period. Thus, all 5400 rpm drives of any make or model have 5.56 ms latency; all 7200 rpm drives, 4.17 ms; all 10,000 rpm drives, 3.0 ms; and all 15,000 rpm drives have 2.0 ms latency. Like seek time, latency is a critical performance factor and is always measured in milliseconds. (More on latency.)

- The **internal data rate** is the speed with which the drive's internal read channel can transfer data from the magnetic media. (Or, less commonly, in the reverse direction.) Previously a very important factor in drive performance, it remains significant but less so than in prior years, as all modern drives have very high internal data rates. Internal data rates are normally measured in Mega*bits* per second (Mbit/s).

Subsidiary performance factors include:

- **Access time** is simply the sum of the seek time and the latency. It is important not to mistake seek time figures for access time figures! The access time is by far the most important performance benchmark of a modern HDD. It almost alone defines how fast the disk performs in a typical system. However, people tend to pay much more attention to the data rates, which rarely make any significant difference in typical systems. Of course, in some usage scenarios it may be vise-versa, so you need to know your system before buying a HDD.

- The **external data rate** is the speed with which the drive can transfer data from its buffer to the host computer system. Although in theory this is vital, in practice it is usually a non-issue. It is a relatively trivial matter to design an electronic interface capable of outpacing any possible mechanical read/write mechanism, and it is routine for computer makers to include a hard drive controller interface that is significantly faster than the drive it will be attached to. As a general rule, modern ATA and SCSI interfaces are capable of dealing with at least twice as much data as any single drive can deliver; they are, after all, designed to handle two or more drives per bus even though a desktop computer usually mounts only one. For a single-drive computer, the difference between ATA-100 and ATA-133, for example, is largely one of marketing rather than performance. No drive yet manufactured can utilise the full bandwidth of an ATA-100 interface, and few are able to send more data than an ATA-66 interface can accept. The external data rate is usually measured in MB/s or MiB/s.

- **Command overhead** is the time it takes the drive electronics to

interpret instructions from the host computer and issue commands to the read/write mechanism. In modern drives it is negligible.

Access and interfaces

A hard disk is generally accessed over one of a number of bus types, including ATA (IDE, EIDE), SCSI, FireWire/IEEE 1394, USB, and Fibre Channel. In late 2002 Serial ATA was introduced.

Back in the days of the ST-506 interface, the data encoding scheme was also important. The first ST-506 disks used Modified Frequency Modulation (MFM) encoding (which is still used on the common "1.44 MB" (1.4 MiB) 3.5-inch floppy), and ran at a data rate of 5 megabits per second. Later on, controllers using *2,7 RLL* (or just "RLL") encoding increased this by half, to 7.5 megabits per second; it also increased drive capacity by half.

Many ST-506 interface drives were only certified by the manufacturer to run at the lower MFM data rate, while other models (usually more expensive versions of the same basic drive) were certified to run at the higher RLL data rate. In some cases, the drive was overengineered just enough to allow the MFM-certified model to run at the faster data rate; however, this was often unreliable and was not recommended. (An RLL-certified drive could run on a MFM controller, but with 1/3 less data capacity and speed.)

ESDI also supported multiple data rates (ESDI drives always used 2,7 RLL, but at 10, 15 or 20 megabits per second), but this was usually negotiated automatically by the drive and controller; most of the time, however, 15 or 20 megabit ESDI drives weren't downward compatible (i.e. a 15 or 20 megabit drive wouldn't run on a 10 megabit controller). ESDI drives typically also had jumpers to set the number of sectors per track and (in some cases) sector size.

SCSI originally had just one speed, 5 MHz (for a maximum data rate of 5 megabytes per second), but this was increased dramatically later. The SCSI bus speed had no bearing on the drive's internal speed because of buffering between the SCSI bus and the drive's internal data bus; however, many early drives had very small buffers, and thus had to be reformatted to a different interleave (just like ST-506 drives) when used on slow computers, such as early IBM PC compatibles and Apple Macintoshes.

ATA drives have typically had no problems with interleave or data rate, due to their controller design, but many early models were incompatible with each other and couldn't run in a master/slave setup (two drives on the same cable). This was mostly remedied by the mid-1990s, when ATA's specfication was standardised and the details begun to be cleaned up, but still causes problems occasionally (especially with CD-ROM and DVD-ROM drives, and when mixing Ultra DMA and non-UDMA

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devices). Serial ATA does away with master/slave setups entirely, placing each drive on its own channel (with its own set of I/O ports) instead.

Other characteristics

- Capacity (measured in gigabytes)
- MTBF (mean time between failures)
- Power consumption (especially important in battery-powered laptops)
- audible noise (in dBA)
- G-shock rating (surprisingly high in modern drives)

Addressing modes

There are two modes of addressing the data blocks on more recent hard disks. The older one is the CHS addressing (Cylinder-Head-Sector), used on old ST-506 and ATA drives and internally by the PC BIOS, and the more recent one the LBA (Logical Block Addressing), used by SCSI drives and newer ATA drives (ATA drives power up in CHS mode for historical reasons).

CHS describes the disk space in terms of its physical dimensions, data-wise; this is the traditional way of accessing a disk on IBM PC compatible hardware, and while it works well for floppies (for which it was originally designed) and small hard disks, it caused problems when disks started to exceed the design limits of the PC's CHS implementation. The traditional CHS limit was 1024 cylinders, 16 heads and 63 sectors; on a drive with 512-byte sectors, this comes to 504 MiB (528 megabytes). The origin of the CHS limit lies in a combination of the limitations of IBM's BIOS interface (which allowed 1024 cylinders, 256 heads and 64 sectors; sectors were counted from 1, reducing that number to 63, giving an addressing limit of 8064 MiB or 7.8 GiB), and a hardware limitation of the AT's hard disk controller (which allowed up to 65536 cylinders and 256 sectors, but only 16 heads, putting its addressing limit at 2^28 bits or 128 GiB).

When drives larger than 504 MiB began to appear in the mid-1990s, many system BIOSes had problems communicating with them, requiring LBA BIOS upgrades or special driver software to work correctly. Even after the introduction of LBA, similar limitations reappeared several times over the following years: at 2.1, 4.2, 8.4, 32, and 128 GiB. The 2.1, 4.2 and 32 GiB limits are *hard limits*: fitting a drive larger than the limit results in a PC that refuses to boot, unless the drive includes special jumpers to make it appear as a smaller capacity. The 8.4 and 128 GiB limits are *soft limits*: the PC simply ignores the extra capacity and reports a drive of the maximum size it is able to communicate with.

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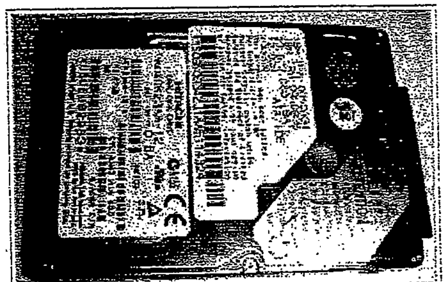
SCSI drives, however, have always used LBA addressing, which describes the disk as a linear, sequentially-numbered set of blocks. SCSI mode page commands can be used to get the physical specifications of

the disk, but this is not used to read or write data; this is an artifact of the early days of SCSI, circa 1986, when a disk attached to a SCSI bus could just as well be an ST-506 or ESDI drive attached through a bridge (and therefore having a CHS configuration that was subject to change) as it could a native SCSI device. Because PCs use CHS addressing internally, the BIOS code on PC SCSI host adapters does CHS-to-LBA translation, and provides a set of CHS drive parameters that tries to match the total number of LBA blocks as closely as possible.

ATA drives can either use their native CHS parameters (only on very early drives; hard drives made since the early 1990s use multiple-zone recording, and thus don't have a set number of sectors per track), use a "translated" CHS profile (similar to what SCSI host adapters provide), or run in ATA LBA mode, as specified by ATA-2. To maintain some degree of compatibility with older computers, LBA mode generally has to be requested explicitly by the host computer. ATA drives larger than 8 GiB are always accessed by LBA, due to the 8 GiB limit described above.

See also: hard disk drive partitioning, master boot record, file system, drive letter assignment, boot sector.

Manufacturers



Hitachi 2.5 inch laptop hard drive

Most of the world's hard disks are now manufactured by just a handful of large firms: Seagate, Maxtor, Western Digital, Samsung, and the former drive manufacturing division of IBM, now sold to Hitachi. Fujitsu continues to make specialist notebook and SCSI drives but exited the mass market in 2001. Toshiba is a major manufacturer of 2.5-inch notebook drives.

Firms that have come and gone

Dozens of former hard drive manufacturers have gone out of business, merged, or closed their hard drive divisions; as capacities and demand for products increased, profits became hard to find, and there were shakeouts in the late 1980s and late 1990s. The first notable casualty of the business in the PC era was Computer Memories International or CMI; after the 1985 incident with the faulty 20MB AT drives, CMI's reputation never recovered, and they exited the hard drive business in 1987. Another notable failure was MiniScribe, who went bankrupt in 1990 after it was found that they had "cooked the books" and inflated sales numbers for several years. Many other smaller companies (like Kalok, Microscience, LaPine, Areal, Priam and PrairieTek) also did not

survive the shakeout, and had disappeared by 1993; Micropolis was able to hold on until 1997, and JTS, a relative latecomer to the scene, lasted only a few years and was gone by 1999. Rodime was also an important manufacturer during the 1980s, but stopped making drives in the early 1990s amid the shakeout and now concentrates on technology licensing; they hold a number of patents related to 3.5-inch form factor hard drives.

There have also been a number of notable mergers in the hard disk industry:

- Tandon sold its disk manufacturing division to Western Digital (which was then a controller maker and ASIC house) in 1988; by the early 1990s Western Digital disks were among the top sellers.
- Quantum bought DEC's storage division in 1994, and later (2000) sold the hard disk division to Maxtor to concentrate on tape drives.
- In 1995, Conner Peripherals announced a merger with Seagate (who had earlier bought Imprimis from CDC), which completed in early 1996.
- JTS infamously merged with Atari in 1996, giving it the capital it needed to bring its drive range into production.
- In 2003, following the controversy over the mass failures of the Deskstar 75GXP range (which resulted in lost sales of its follow-ons), hard disk pioneer IBM sold the majority of its disk division to Hitachi, who renamed it *Hitachi Global Storage Technologies*.

"Marketing" capacity versus true capacity

It is important to note that hard drive manufacturers often use the metric definition of the prefixes "giga" and "mega." However, nearly all operating system utilities report capacities using binary definitions for the prefixes. This is largely historical, since when storage capacities started to exceed thousands of bytes, there were no standard binary prefixes (the IEC only standardized binary prefixes in 1999), so 2^{10} (1024) bytes was called a kilobyte because 1024 is "close enough" to the metric prefix kilo, which is defined as 10^3 or 1000. This trend became habit and continued to be applied to the prefixes "mega," "giga," and even "tera." Obviously the discrepancy becomes much more noticible in reported capacities in the multiple gigabyte range, and users will often notice that the volume capacity reported by their OS is significantly less than that advertised by the hard drive manufacturer. For example, a drive advertised as 200 GB can be expected to store close to 200 x 10^9, or 200 billion, bytes. This uses the proper SI definition of "giga," 10^9 and cannot be considered as incorrect. Since utilities provided by the operating system probably define a Gigabyte as 2^{30}, or 1073741824, bytes, the reported capacity of the drive will be closer to 186.26 GB (actually, GiB), a difference of well over ten gigabytes. For this very reason, many utilities that report capacity have begun to use the aforementioned IEC standard binary prefixes (e.g. KiB, MiB, GiB) since their definitions are not ambiguous.

Another side point is that many people mistakenly attribute the discrepancy in reported and advertised capacities to reserved space used for file system and partition accounting information. However, this data rarely occupies more than several KiB or a few MiB, and therefore cannot possibly account for the apparent "loss" of tens of Gigabytes.

Hard disk usage

From the original use of a hard drive in a single computer, techniques for guarding against hard disk failure were developed such as the redundant array of independent disks (RAID). Hard disks are also found in network attached storage devices, but for large volumes of data are most efficiently used in a storage area network.

History

The first computer with a hard disk drive as standard was the IBM 350 Disk File, introduced in 1955 with the IBM 305 computer. This drive had fifty 24 inch platters, with a total capacity of five million characters. In 1952, an IBM engineer named Reynold Johnson developed a massive hard disk consisting of fifty platters, each two feet wide, that rotated on a spindle at 1200 rpm with read/write heads for the first database running RCAs Bismark computer.

In 1973, IBM introduced the 3340 "Winchester" disk system (the 30MB + 30 millisecond access time led the project to be named after the Winchester 30-30 rifle), the first to use a sealed head/disk assembly (HDA). Almost all modern disk drives now use this technology, and the term "Winchester" became a common description for all hard disks, though generally falling out of use during the 1990s.

For many years, hard disks were large, cumbersome devices, more suited to use in the protected environment of a data center or large office than in a harsh industrial environment (due to their delicacy), or small office or home (due to their size and power consumption). Before the early 1980s, most hard disks had 8-inch or 14-inch platters, required an equipment rack or a large amount of floor space (especially the large removable-media drives, which were often referred to as "washing machines"), and in many cases needed special power hookups for the large motors they used. Because of this, hard disks were not commonly used with microcomputers until after 1980, when Seagate Technology introduced the ST-506, the first 5.25-inch hard drive, with a capacity of 5 megabytes. In fact, in its factory configuration the original IBM PC (IBM 5150) was not equipped with a hard drive.

Most microcomputer hard disk drives in the early 1980s were not sold under their manufacturer's names, but by OEMs as part of larger peripherals (such as the Corvus Disk System and the Apple ProFile). The IBM PC/XT had an internal hard disk, however, and this started a trend toward buying "bare" drives (often by mail order) and installing them directly into a system. Hard disk makers started marketing to end users

as well as OEMs, and by the mid-1990s, hard disks had become available on retail store shelves.

While internal drives became the system of choice on PCs, external hard drives remained popular for much longer on the Apple Macintosh and other platforms. Every Mac made between 1986 and 1998 has a SCSI port on the back, making external expansion easy; also, "toaster" Macs did not have easily accessible hard drive bays (or, in the case of the Mac Plus, any hard drive bay at all), so on those models, external SCSI disks were the only reasonable option. External SCSI drives were also popular with older microcomputers such as the Apple II series and the Commodore 64, and were also used extensively in servers, a usage which is still popular today. The appearance in the late 1990s of high-speed external interfaces such as USB and IEEE 1394 (FireWire) has made external disk systems popular among regular users once again, especially for users that move large amounts of data between two or more locations, and most hard disk makers now make their disks available in external cases.

The capacity of hard drives has grown exponentially over time. With early personal computers, a drive with a 20 megabyte capacity was considered large. In the latter half of the 1990's, hard drives with capacities of 1 gigabyte and greater became available. As of early 2005, the "smallest" desktop hard disk in production has a capacity of 40 gigabytes, while the largest-capacity drives approach one half terabyte (500 gigabytes), and are expected to exceed that mark by year's end.

As far as PC history is concerned - the major drive families have been MFM, RLL, ESDI, SCSI, IDE, EIDE, and now SATA. MFM drives required that the electronics on the "controller" be compatible with the electronics on the card - disks and controllers had to be compatible. RLL (Run Length Limited) was a way of encoding bits onto the platters that allowed for better density. Most RLL drives also needed to be "compatible" with the controllers that communicated with them. ESDI was an interface developed by Maxtor. It allowed for faster comminication between the PC and the disk. SCSI (originally named SASI for Shuman (sic) Associates) or Small Computer System Interface was an early competitor with ESDI. When the price of electronics dropped (and because of a demand by consumers) the electronics that had been stored on the controller card was moved to the disk drive itself. This advance was known as "Independent Drive Electronics" or IDE. Eventually, IDE manufacturers wanted the speed of IDE to approach the speed of SCSI drives. IDE drives were slower because they did not have as big a cache as the SCSI drives, and they could not write directly to RAM. IDE manufacturers attempted to close this speed gap by introducing Logical Block Addressing (LBA). These drives were known as EIDE. While EIDE was introduced, though, SCSI manufacturers continued to improve SCSI's performance. The increase in SCSI performance came at a price -its interfaces were more expensive. In order for EIDE's performance to increase (while keeping the cost of the associated electronics low), it was realized that the only way to do this

was to move from "parallel" interfaces to "serial" interfaces, the result of which is the SATA interface. Fiber channel interfaces are left to discussions of server drives.

See also

- Early IBM disk storage

External links

- The PC Guide: A Brief History of the Hard Disk Drive
- Binary versus Decimal
- Multi Disk System Tuning HOWTO
- Windows NT Server Resource Kit: Disk Management Basics (See section "About Disks and Disk Organization")
- Behold the God Box - Less's Law and future implications of massive cheap hard disk storage

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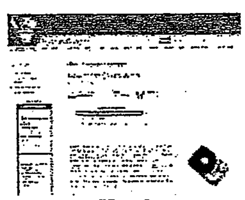

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